§5. Evaluation of Energy Payback Ratio (EPR) of Tokamak Reactors

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Global warming due to rapid greenhouse gas (GHG) emission is a serious environmental problem, and fusion reactors are expected as one of safe and abundant electric power systems to reduce GHG emission amounts. To search for economic, environment-friendly and energy-efficient fusion reactors, system studies have been carried out taking care of life-cycle cost of electricity (COE), carbon dioxide gas emission rate (CO_2) and energy payback ratio (EPR) for various fusion reactors. It was shown that these values critically depend on achievable beta and current drive efficiency for tokamak reactors, and on driver energy and repetition rate for inertial fusion reactors. Scaling formulas on COE, CO_2 and EPR are derived through extensive analyses[1-3].

The physics, engineering and economics of fusion reactors are evaluated by the PEC (Physics-Engineering-Cost) system code for magnetic fusion reactors (tokamak (TR), spherical tokamak (ST) and helical (HR)) and inertial fusion reactors (IR). The magnetic fusion reactor designs strongly depend on achievable plasma beta value and magnetic field strength, and inertial fusion reactors depend on the driver energy and driver repetition rate. After the radial-build analysis by the PEC code, detailed burning plasma assessments including bootstrap current analysis are carried out using 1.5-dimentional TOTAL (Toroidal Transport Analysis Linkage) simulation code. The life-cycle CO_2 emission equivalently including methane gas is evaluated for several blanket designs using the input-output table method. In the present TR reference analysis, the maximum field of superconducting coil is assumed 13 T. The tolerable neutron wall fluence is assumed to be 20MWYr/m^2 in the case of LiPb/SiC blanket system, which determines the replacement cycle of blanket modules leading to radioactive waste disposals.

The cost and energy values critically depend on reactor physics parameters such as normalized beta β_N and current drive (CD) efficiency f_{CD}. In the PEC code the bootstrap current fraction is based on ITER design formula ($I_{BS} / Ip \propto (\varepsilon^{1/2}\beta_p)^{1.3}$), and the assumed CD power is given by

$$P_{CD}(MW) = 2n_e(10^{20}m^{-3})R_p(m)(I_p - I_{BS}(MA)) / f_{CD}\,.$$

To reduce COE and raise EPR, high CD efficiency (f_{CD} > 1.0) is required for low-beta (β_N <4) reactor designs (Fig.1). Various analyses have been carried out focusing on EPR for ST reactors[4-5] and on COE for D-T, D-3He, and catalyzed D-D Fusion reactors[6-7].

Large-sized reactors such as helical reactors look worse than compact reactors from the view-point of cost and energy. However, large and conservative reactors seem generally safer than compact and high performance designs. The accident risk probability and related settlement expenditures, in addition to CO_2 environmental tax, should be included in the future assessment for the comparisons with other electric power generation systems.

1) Yamazaki, K., Ban, K., Oishi, T. and Arimoto, H., 24th Fusion Energy Conference (2012-IAEA) San Diego, USA 8-13 October 2012, SEE/P7-02.
2) Yamazaki, K., Oishi, T. and Arimoto, H., Plasma Fusion Res. **7** (2012) 2405082.
3) Yamazaki, K., Oishi, T., Ban, K., Kondo, T., Arimoto, H. and Nagayama Y., IEEJ Transactions on Fundamentals and Materials **132** (2012) 526.
4) Ban, K., Yamazaki, K., Arimoto, H., Oishi, T. and Shoji, T., Plasma Fusion Res. **7** (2012) 2405119.
5) Ban, K., Yamazaki, K., Arimoto, H., Oishi, T. and Shoji, T., IEEJ Transactions on Fundamentals and Materials **132** (2012) 535.
6) Kondo, T., Yamazaki, K., Oishi, T., Arimoto H. and Shoji, T., Plasma Fusion Res. **7** (2012) 2405067.
7) Oishi, T., Yamazaki, K., Arimoto, H., Ban, K., Kondo, T., Tobita, K. and Goto, T., Plasma Fusion Res. **7** (2012) 2405115.

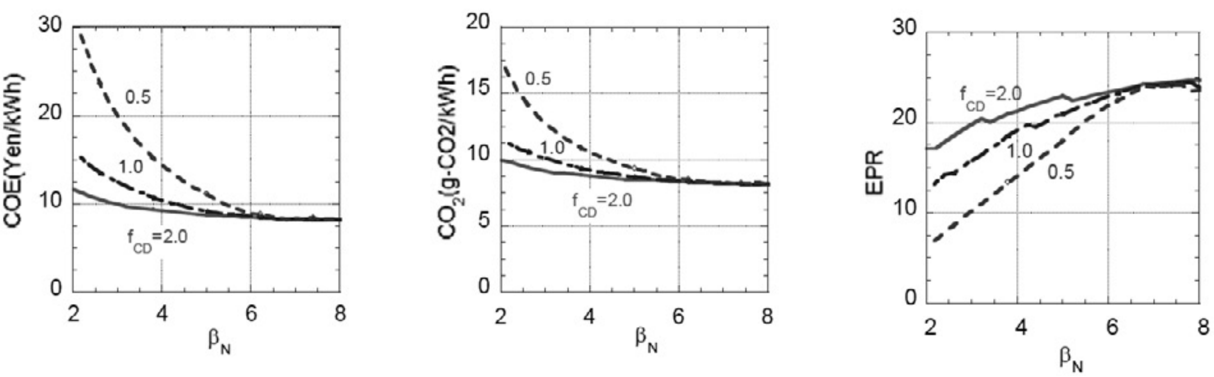

Fig.1 Effect of current drive efficiency f_{CD} on COE, CO_2 emission rate and EPR as a function of normalized beta β_N for 1 GWe tokamak reactors.